What Did I Sniff? Mapping Scents Onto Driving-Related Messages

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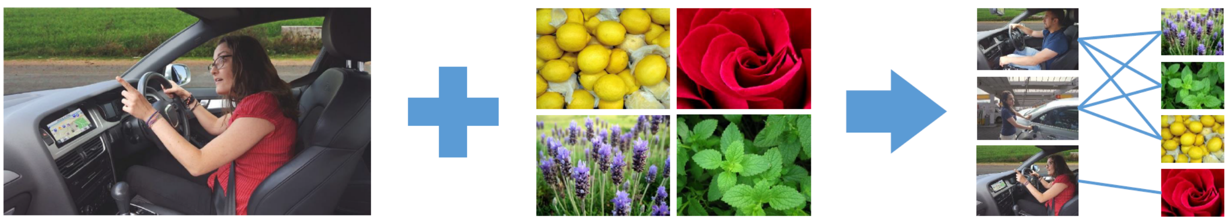

(a) Message (b) Scents (c) Mapping

Figure 1: Steps in our research on the investigation of the mapping between informative messages in the driving context and scents: (a) choosing a set of driving-relevant messages, (b) selecting a set of scents, and (c) mapping the scents onto the messages.

ABSTRACT

The sense of smell is well known to provide very vivid experiences and to mediate a strong activation of crossmodal semantic representations. Despite a growing number of olfactory HCI prototypes, there have been only a few attempts to study the sense of smell as an interaction modality. Here, we focus on the exploration of olfaction for in-car interaction design by establishing a mapping between three different driving-related messages ("Slow down", "Fill gas", "Passing by a point of interest") and four scents (lemon, lavender, peppermint, rose). The results of our first study demonstrate strong associations between, for instance, the "Slow down" message and the scent of lemon, the "Fill gas" message and the scent of peppermint, the "Passing by a point of interest" message and the scent of rose. These findings have been confirmed in our second study, where participants expressed their mapping preferences while performing a simulated driving task.

CCS Concepts

• **Human-centered computing∼Empirical studies in HCI**
• *Human-centered computing∼Interaction techniques*

Author Keywords

Olfaction; Smell; Mapping; Odour Stimulation; Automotive User Interfaces; Multimodal Interfaces; In-Car Interaction; Car-Driver Interaction; Semantic Information Layer.

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INTRODUCTION

The sense of smell is the most complex and challenging human sense (see [3, 24, 44]), but at the same time, it is a very powerful interaction medium enabling humans to extract meaningful information [43]. It has been shown that odours trigger automatic and implicit retrieval of mental representations related to the odour source [8], and enable automatic access to terms semantically related to the odours [19]. Moreover, the congruence between visual and olfactory information, and consequently multiple sensory sources, mediates the activation of crossmodal semantic representations stronger than each sensory modality on its own [43]. Considering that driving is a multisensory process, where eyes, ears, and limbs are all coordinated to get the task done, an olfactory component could make multimodal in-car interfaces even more efficient.

The positive effect of smell on driving has been evidenced by a number of studies [30, 5, 39, 49, 36, 16]. In fact, in 2013 Ford has patented the in-vehicle smell notification system [26], while Mercedes-Benz and BMW have already installed the olfactory interfaces in their S-Class[1] and 7 Series[2] vehicles. The latter two are however mainly used as ambient scent-delivery devices to merely improve the hedonic experiences of the drivers, not fully exploiting the potential of the sense of smell in the context of driving. Our research builds on this work, in particular, to alert the driver about driving-relevant information. We believe that olfaction is interesting with respect to introducing a new semantic layer into interaction design and HCI (such as the mapping between different scents and messages related to the task of driving).

[1] `https://www.mercedes-benz.com/en/mercedes-benz/innovation/a-fragrance-for-the-new-s-class/`
[2] `http://www.bmwblog.com/2015/07/03/she-created-the-smell-of-the-all-new-bmw-7-series/`

To address the above challenge, it is first of all necessary to define the characteristics of the driving-related messages and scents, and the relationship between them, so as to avoid performing tests with arbitrary scents, and to create an empirically grounded starting point for in-car olfactory interface design. To find out when the use of olfactory stimuli is meaningful in the car, we developed a two-dimensional framework to define driving-relevant messages, which either require "low or high attention" and "slow or fast reaction" from the driver. We account for the level of alertness of information and the required response time. Accordingly, we also selected a set of two alerting (lemon, peppermint) and two relaxing (lavender, rose) scents to carry out our studies. In Study 1, we used a four-step procedure to establish an objective mapping between three messages and four scents. We then extracted three best-rated scents and confirmed the mapping established in Study 1 by asking the participants to express their mapping preferences while performing a simulated driving task in Study 2.

We discuss the findings with respect to the potential of specific scents to convey particular information, considering the perceived alertness, relaxation, and urgency of the informative messages, as well as the alertness and relaxation levels of the scents. Our findings show that the scents of lemon, lavender, and peppermint are useful for alerting and urgent messages ("Slow down" and "Fill gas"), while the scent of rose is linked to relaxing messages ("Passing by a point of interest").

The main contributions of this paper are

i. presentation of a new semantic layer based on an empirical investigation of driving-related messages and scents,

ii. extraction of specific design considerations for guiding smell-based in-car interaction design.

RELATED WORK

Expanding In-Car Interaction Modalities

Within the driving context, vision is the dominant sense, and any distraction of the driver's visual attention on the road can have fatal consequences [38]. This is especially important to consider with the increasing amount of information the car is sending to the driver. Auditory stimulation can reduce the visual load and even increase the urgency perception of the warnings [12], but also be annoying [4] or even distracting [12]. Application of tactile interaction demonstrated, for instance, a positive effect on users' attention in safety critical environments [45], and faster braking reaction times [29] in simulated driving. However, none of these approaches takes advantage of the sense of smell, in particular of its positive impact on crossmodal correspondences [43], and the relationship between odour detection and semantically congruent cues [17] that it provides. Here, we propose a novel approach investigating the use of odours as an information medium.

No other sensory modality (besides olfaction) has a direct and intense contact with the neural substrates of emotion and memory, which may explain why smell-evoked memories are usually emotionally potent. The emotion-eliciting effect of smell is particularly useful in inducing mood changes because they are almost always experienced clearly as either pleasant or unpleasant [13]. For instance, Alaoui-Ismaïli et al. [1] used the scents of vanillin and menthol to trigger positive emotions in their participants (mainly happiness and surprise), as well as methyl methacrylate and propionic acid to trigger negative emotions (mainly disgust and anger). The understanding of smell established by neuroscientists and cognitive psychologists provides a strong starting point for investigating the relation between specific scents and experiences.

Establishing a Semantic Layer Through Smell

Previous studies on olfaction in psychology provide valuable insights into the semantics elicited by the sense of smell. For instance, Seigneuric et al. [43] highlighted that odours can affect visual processing by capturing people's attention. This is especially important since congruency between visual and olfactory information mediates the activation of crossmodal semantic representations much stronger than each sensory modality on its own [43]. Previous findings in psychology also showed the arousing [5, 39, 23] and relaxing [31, 28, 20, 15] effects of different scents on humans, which is very important to consider in the design of interactive olfactory interfaces in HCI. This prior work indicates the potential to convey basic, but yet informative messages, to a person (i.e. different levels of alertness, relaxation, and urgency) by means of olfactory stimulation.

The relationship between odour detection and semantically congruent cues has been demonstrated by Gottfried et al. [17]. Castiello et al. [8] have also shown that odours can influence our motor action, giving hints to the task of grasping, because smell triggers automatic and implicit retrieval of a mental representation of the object the scent is coming from [8]. The same effect has been studied in the scope of accessibility of lexical terms [19]. Seigneuric et al. [43] also pointed out that implicit presentation of odours may influence perception and cognition in human adults, and that the sensorium is massively influenced by vision and audition. This opens up new interaction possibilities in the automotive context.

While scent mapping has been studied for decades outside HCI [11], olfactory human-computer interaction gained increased interest only recently [33, 42, 34]. Nowadays we see a variety of scent delivery devices and technologies appearing on the commercial market [34]. Olfaction has been applied for photo-tagging [7] and ambient notifications [6, 47]. These explorations indicated that smell is less disruptive than visual and auditory stimuli. Despite the growing amount of such works in HCI, there have been only a few works tackling olfactory stimulation in the automotive context. The main contributions are targeting drowsiness while driving [50, 16, 36], alertness and mood of the driver [5, 39], and driving performance task [30]. All these previous studies demonstrate the potential of smell to enhance users' experiences, and in particular, introduce a new way of in-car interaction. Nevertheless, none of these studies has explored a mapping between scents and messages.

In this paper, we extend this emerging field of research by establishing an understanding of how olfactory stimulation can be used to transfer specific information to the user, in our case to the driver. For that purpose, our experiments explored the mapping between driving-relevant information and scents.

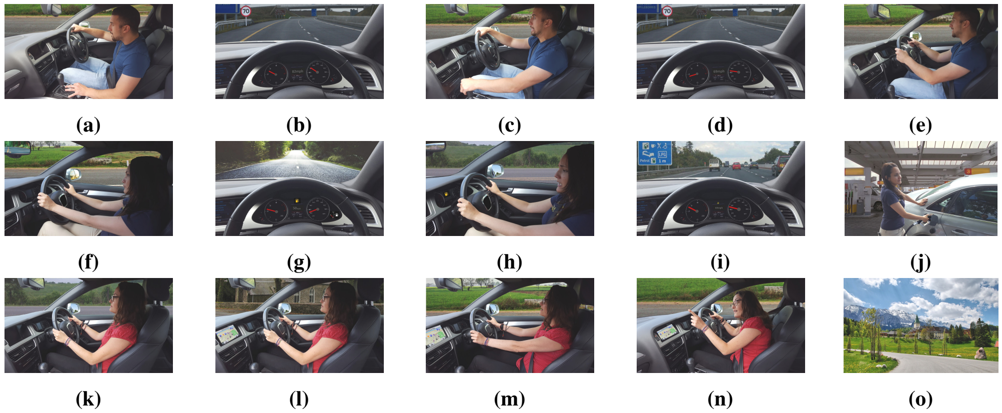

Figure 2: "Slow down" (a-e), "Fill gas" (f-j), and "Passing by a point of interest" (k-o) storylines. Each storyline consists of five static images presented one-by-one to the participants in Study 1 to explain the context of each driving-related message.

DRIVING RELATED INFORMATION

In order to investigate how smell can convey specific driving-relevant information, we defined three typical driving scenarios represented by following three messages: (1) "Slow down", (2) "Fill gas", and (3) "Passing by a point of interest".

These messages were selected based on a two-dimensional framework (see Figure 3). We accounted for the level of alertness and required reaction time in the described situation, which characterised the alertness and urgency of the message to be conveyed to the driver. We split the alertness dimension into a "low" and a "high" range, but the reaction time dimension into a "fast" and "slow", dividing our space into four areas. We filled each area, apart from one, with a dedicated driving relevant message. It is not common to have a message with a low level of alertness, which at the same time requires a quick response (high urgency) within a driving context. For this reason, we did not specify a message for that area. For the remaining three areas, we chose "Slow down" for high alertness and fast reaction time, "Fill gas" for high alertness, slow reaction time, and "Passing by a point of interest" for low alertness, slow reaction time, which consequently is the least urgent situation from the driver's primary driving task perspective. The main criteria for choosing these messages was their relatively long reaction time requirement (not a high priority information, which requires the driver to respond to it in a matter of seconds, considering the time delay between the release and the perception of the scent). In the future, when we know that we can deliver the scent to the user within an even shorter time frame, we will extend the set of messages including high priority information (e.g. an indication of excessive lane deviations or a short inter-vehicle distance).

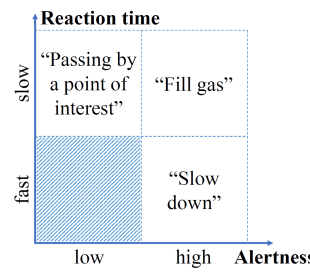

Figure 3: 2D framework of message urgency along two axes: alertness (i.e. salience: low-high) and reaction time (range estimation considering the time required to detect a scent: fast($\leq$10s)-slow($>$10s)).

STUDY 1

In the first study, we presented each of the explored driving-related messages to the participants in the form of short storylines [18] to facilitate the storytelling related to each message over the time (Figure 2), without yet introducing any novel interfaces or interaction elements related to smell:

"Slow down": (2a) Mark is driving on the motorway and at some point, he turns up the volume of the radio to listen to his favourite song. (2b) Without noticing, he is speeding up and begins to drive faster than the speed limit. (2c) At this point, a scent inside the car is released and reminds Mark to slow down. (2d) Mark slows down and is below the speed limit again. (2e) Mark continues listening to music.

"Fill gas": (2f) Sarah is an occasional driver. (2g) She does not need to fill gas every day and has no routine for this activity. (2h) Today she is driving to work and at some moment a scent is released in the car to notify her about the low fuel level. When perceiving the scent, Sarah knows that it is time to fill gas. (2i) After 15min of driving, she sees a "Petrol Station in 1 mile" sign and pulls over in 1 mile. (2j) Sarah fills the tank.

"Passing by a point of interest": (2k) Laura is driving through a new area on the countryside and is eager to explore new sites. (2l) She switches on the navigation system, which is showing all the points of interest on the screen, but as she is driving alone, it is easy to miss a sightseeing place, since she has to focus on the road. (2m) At some point, a scent is released in the car notifying her about an upcoming landmark worth visiting. (2n) A few moments later, Laura notices a beautiful castle on her way. (2o) She decides to stop and visit this castle.

Study Design

This study followed a 5(scents)$\times$3(messages) within-participants experimental design, composed of four main steps: (1) Rating of the perceived level of alertness, relaxation, and urgency of the three presented messages; (2) Mapping between the presented messages and five olfactory stimuli; (3) Ranking of all three messages according to each of the five olfactory stimuli; (4) Rating of the perceived level of alertness, relaxation, and liking of each olfactory stimulus (scent or water). All the stimuli were presented one-by-one in a counterbalanced and randomised order. Overall, the study lasted about 30 minutes.

Scent Selection and Presentation

For the olfactory stimuli, we selected two low arousal (lavender, rose), two high arousal scents (lemon, peppermint), and water as a neutral/control stimulus. All scents were *"miaroma"* 100% pure essential oils from Holland & Barrett Int. Ltd.

These five stimuli were selected based on prior work. Lavender and rose demonstrated a relaxing effect on people (see [31, 28, 20, 15]), while lemon and peppermint were used to increase alertness (see [5, 39, 23]). The scents of lemon and peppermint have already been extensively used in a number of simulated driving studies [30, 5, 39, 49, 36, 16].

All olfactory stimuli were presented to participants in the form of five jars. This manual delivery approach was used in previous studies in the fields of neuroscience and experimental psychology, such as by Khan et al. [25] to investigate their odour pleasantness prediction framework, and more recently by Velasco et al. [46] to study the crossmodal effects of music and odour pleasantness on olfactory quality perception.

At this point, it is worth noting that we initially started the experiment by using a commercially available scent-delivery device, however after having completed the pilot study with 10 participants, we noticed that participants had difficulties in discriminating the stimuli due to the mixing of scents caused by the device. We carefully cleaned the device with ethanol (as instructed by the manufacturer), and left it to dry for 2 hours, but it didn't solve the contamination problem. Hence we decided to change the scent presentation mode. We switched to the manual approach and started a new set of data collection. However, we intended to come back to an automated delivery approach for Study 2. We planned to finish building our own scent-delivery device by the beginning of our second study.

To keep the stimulation constant across the participants, each jar was filled with 5g of the essential oil or water, controlling scent intensity and the weight of the jars. Each jar was also wrapped in paper (odourless) to avoid visual cues with respect to the colour of the liquid. The experimenter was passing the jars one-by-one to the participants based on the predefined randomised protocol. The participants could not see the jar until it was handed to them. They were instructed to hold the jar 2cm away from their nose while sniffing and to perform one sniff (2-5s long) for each jar, in each new trial. Such short sniffing time was designed to avoid any potential olfactory adaptation [35]. A break of 20-25s was ensured between the olfactory stimuli [46] to "refresh" participants' scent perception.

Setup

The experiment was set up in a quiet and well-ventilated room. The participants were sitting in front of a 24" screen with 60Hz refresh rate, on which the driving-related messages were presented through an MS PowerPoint® presentation. Each message consisted of five slides showing one picture after another with a short description. Participants used the keyboard to switch from one slide to the next or the previous if needed.

Procedure and Method

Upon arrival, participants were given the information sheet, an explanation of the procedure, and a consent form to sign.

After presenting each of the three storylines to participants (step 1), they were asked to rate the following three self-report questions on a 7-Point Likert scale: (1) *"How alerting do you consider the message presented in this storyline? (1= "Not alerting at all"; 7= "Very alerting")"*; (2) *"How relaxing do you consider the message presented in this storyline? (1= "Not relaxing at all"; 7= "Very relaxing")"*; (3) *"How urgently would you react to the message presented in this storyline? (1= "Not urgently at all"; 7= "Very urgently")"*.

After having answered these questions, participants were given a jar to sniff and rated the following self-report question on a 7-Point Likert scale (step 2): *"How much do you think this scent represents the message from this storyline? (1= "Very little"; 7= "Very much")"*. This was repeated five times for each storyline, for a total of five olfactory stimuli.

For step 3, participants were given each jar again and asked to rank the suitability of each message to each scent based on the following instructions: *"If you think of smell as a medium to convey information, which message ("Fill gas", "Slow down", or "Passing by a point of interest") would you assign this smell to? (1= "is the best to convey this message", 3= "is the worst to convey this message"). Please do not repeat the ranks."*

Finally, in step 4, we asked participants to rate each olfactory stimulus (independently from a driving-related message) following three self-report questions: (1) *"How alerting is this scent for you? (1= "Not alerting at all"; 7= "Very alerting")"*; (2) *"How relaxing is this scent for you? (1= "Not relaxing at all"; 7= "Very relaxing")"*; (3) *"How much do you like this scent? (1= "I don't like it at all"; 7= "I like it very much")"*.

We designed this questionnaire based on psychometric standard guidelines (self-report based on Likert scale) and used related studies as an example [5, 43]. As conveying information using smell is a relatively unexplored topic, we couldn't adopt any existing questionnaires. We also included typical questions on liking, pleasantness, and relaxation [46, 9]. The experiment was concluded with the demographic questionnaire (age, gender, country(ies) of origin and residence).

Results

In this section, we summarise the main findings from Study 1 following the four main steps described above.

Participants

A total of 30 participants, with a mean age of 31 years (SD= 6.60, 6 females) took part in the study. Participants have reported having no olfactory dysfunctions, adverse reactions to strong smells, respiratory problems, or flu, and not being pregnant. They were recruited on an opportunity-sampling basis.

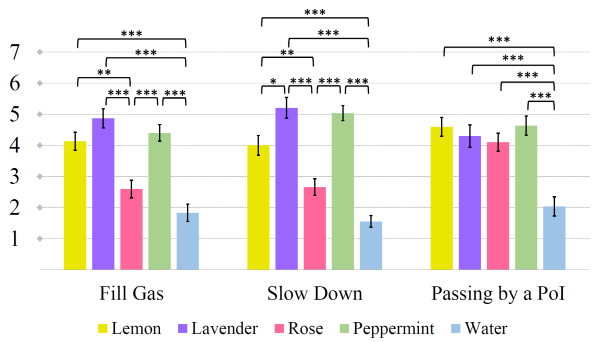

Figure 4: Mean scores of how much each scent represents each of the driving-related messages (1= "Very little"; 7= "Very much"). Error bars, ± s.e.m., $*p < .05$; $**p < .01$; $***p < .001$

The study was approved by the University of Sussex ethics committee. All subjects expressed written consent before the experiment and were rewarded with a £5 Amazon Voucher for their participation.

Message Ratings

To understand how participants perceived the messages, we performed one-way MANOVA considering alertness, relaxation, and urgency as a dependent and driving-related messages as an independent variable. The Post Hoc comparison was performed following the Bonferroni correction.

The results indicate an effect of driving-related messages on the three dependent variables (alertness, relaxation, and urgency), $F(6, 152) = 10.21, p < .001;$ *Wilks'* $\lambda = .508$.

The "Slow down" message (M= 6.10, SD= .80) demonstrated itself as the most alerting (significantly higher than "Fill gas" (M= 5.37, SD= 1.27, p < .05) and "Passing by a point of interest" (M= 4.40, SD= 1.33, p < .001)).

On contrary, the "Passing by a point of interest" message (M= 4.73, SD= 1.34) was chosen as the most relaxing (significantly higher than "Fill gas" (M= 3.00, SD= 1.14, p < .001) and "Slow down" (M= 2.50, SD= 1.45, p < .001)).

Both the "Slow down" (M= 6.26, SD= .86, p < .001) and the "Fill gas" (M= 5.56, SD= 1.30, p < .001) messages were rated significantly more urgent than "Passing by a point of interest" (M= 4.01, SD= 1.55), which matches the Figure 3 framework.

Scent Mapping

To understand the associations between the driving-related messages and each scent, we performed two-way ANOVA, in which messages and scents were the two independent variables, but association rating was a dependent variable. The Post Hoc comparison was used following the Bonferroni correction test.

The results indicate a statistically significant interaction between the messages and the scents ($p < .05$) and a statistically significant difference between the scents ($p < .001$).

Mapping results of the "Fill gas" message (see Figure 4 (left) for details) demonstrate that it was best associated with the scents of lemon (M= 4.13, SD= 1.61), lavender (M= 4.87, SD= 1.70), and peppermint (M= 4.40, SD= 1.43). All of these

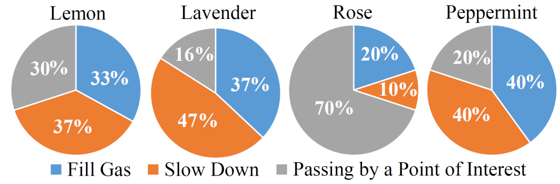

Figure 5: Percentage of subjects having ranked the corresponding driving-related message as first (best) for each scent.

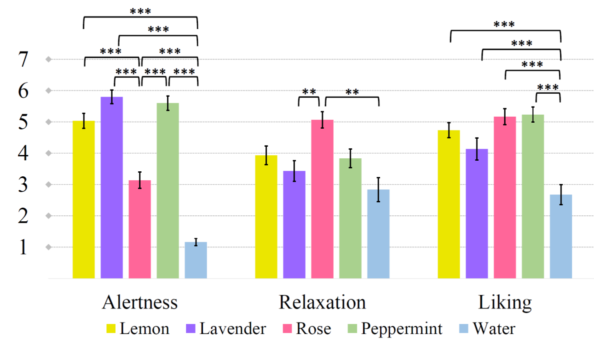

Figure 6: Mean scores of scent alertness, relaxation, and liking. Error bars, ± s.e.m., $*p < .05$; $**p < .01$; $***p < .001$

three scents were rated significantly higher than the scent of rose (M= 2.60, SD= 1.57) and water (M= 1.83, SD= 1.53).

Similarly to the "Fill gas" message, "Slow down" was best mapped onto the scents of lemon (M= 4.00, SD= 1.71), lavender (M= 5.21, SD= 1.80), and peppermint (M= 5.03, SD= 1.29), however lavender was also rated significantly higher than lemon (see Figure 4 (middle)). Lemon, lavender, and peppermint were all rated significantly higher than the scent of rose (M= 2.66, SD= 1.42) and water (M= 1.55, SD= .98).

Mapping onto the "Passing by a point of interest" message shows that water (M= 2.03, SD= 1.67) is rated significantly lower than the scents of lemon (M= 4.60, SD= 1.63), lavender (M= 4.30, SD= 1.97), rose (M = 4.10, SD= 1.60), and peppermint (M= 4.63, SD= 1.69) (see Figure 4 (right)).

Scent Ranking

To compare the participants' rankings of the correspondence between each scent and each message, we performed a non-parametric analysis of the data. The results underline statistically significant differences in the scent-message rankings ($\chi^2(4)= 18.77, p< .001$). In particular, rose has been highly ranked in association with the "Passing by a point of interest" message ($\chi^2(2)= 6.21, p< .05$) (see Figure 5). The other associations are not providing any clear preference for either the scent of lemon, lavender, or peppermint. Important to mention is that we have taken only the messages ranked first (best) for the data analysis, even though participants were asked to rank the second best, and the worst message for each scent. This was done intentionally, to help the participants think more.

Scent Ratings

We evaluated the ratings of the perceived scent attributes (i.e. alertness, relaxation, and liking) performing a one-way MANOVA, considering scents as an independent variable, and alertness/relaxation/liking ratings as a dependent variable. We did the Post Hoc comparison with Bonferroni correction.

The scents of lemon (M= 5.03, SD= 1.30), lavender (M= 5.80, SD= 1.21), and peppermint (M= 5.60, SD= 1.25) were rated significantly more alerting than the scent of rose (M= 3.13, SD= 1.43) and water (M= 1.16, SD= .64) (see Figure 6 (left)).

The scent of rose (M= 5.07, SD= 1.44) was rated significantly more relaxing than both the scent of lavender (M= 3.43, SD= 1.81) and water (M= 2.84, SD= 2.13) (see Figure 6 (middle)).

Finally, the scents of lemon (M= 4.73, SD= 1.31), lavender (M= 4.13, SD= 1.90), rose (M= 5.17, SD= 1.39), and peppermint (M= 5.23, SD= 1.30), were all liked significantly more than water (M= 2.68, SD= 1.78) (see Figure 6 (right)).

Summary

In this study, we found associations between arousing scents (e.g. lemon, peppermint) and alerting/urgent driving-related messages (e.g. "Slow down", "Fill gas"). On contrary, relaxing scents (e.g. rose) were mapped onto less alerting and urgent messages (e.g. "Passing by a point of interest"). To verify these findings, we did a follow-up study in the driving simulator.

STUDY 2

In the second study, we asked the participants to express their mapping preferences between the scents and the messages while performing a simulated driving task.

Study Design

This study followed a 3(scents)×3(messages) within-participants experimental design, composed of two main steps: (1) Familiarisation with the messages and the scents by rating the perceived level of their alertness; (2) Mapping the presented scents onto the messages in the process of driving.

All the stimuli (driving-related messages and scents) were presented one-by-one in a counterbalanced and randomised order. Overall the study lasted about 20 minutes.

Scent Selection and Presentation

For the olfactory stimuli, we selected the scents of rose, lemon, and peppermint, because they had the best associations with the driving-related messages in Study 1 and because the scents of lemon and peppermint have already been applied in numerous simulated driving studies [30, 5, 39, 49, 36, 16]. We used essential oils from the same supplier as in Study 1.

We presented the scents in an automated way by means of a self-made scent-delivery device. The device delivered the air from a tank of compressed clean air. This air was propelled though glass jars (using plastic tubes of 4mm in diameter) filled with 5g of 100% pure essential oils (one jar per scent) with the air pressure of 1 bar in order to diffuse the scent into the delivered air. The output of the scent-delivery device was located behind the steering wheel and pointed towards the participants' face. The distance from the output to the face was 42-66cm (M= 58.06, SD= 6.71), depending on how the participants adjusted their seat. We measured this distance using an ultrasound sensor located just under the output (see Figure 7). The flow of air was controlled using electric valves

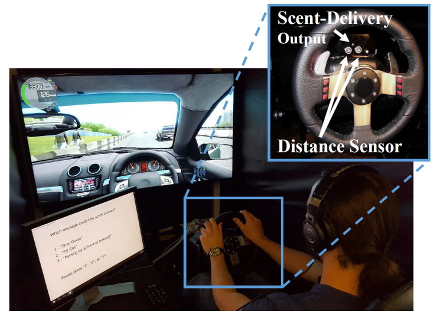

Figure 7: Setup of the driving simulator with an integrated system of automated scent-delivery used for the mapping task.

and an Arduino board connected to a computer. Participants wore headphones playing the sound of the driving simulator software, which was cancelling the sound of the scent-delivery.

Setup

The experiment was set up in our olfactory interaction space, which is a former soft wall clean room (Connect 2 Cleanrooms Ltd., H= 2.1m, W= 1.3m, L= 2m), equipped with an air extractor (Torin-Sifan DDC270-270, 550W, 4 pole, 1 speed, 230V, 50Hz, 1 phase). We exchanged its original walls with the black odourless water-repellent fabric, which does not absorb scents.

The participants were sitting in a driving simulator seat (FK Automotive) equipped with the Logitech G27 steering wheel in front of a 55" curved screen with 60Hz refresh rate, on which the view outside the car from driver's position was rendered. We used the CityCarDriving 1.5 driving simulator software for this purpose. This software was chosen due to the support of left-hand driving and traffic rules. The questions were presented to the participants on a second screen (17", 60Hz refresh rate) located to the left from the steering wheel (see Figure 7). Participants gave their responses to the questions using a numeric keypad located under the second screen.

Procedure and Method

Upon arrival, participants were given the information sheet, an explanation of the procedure, and a consent form to sign.

In step 1, participants were asked to answer three questions about the perceived alertness level of the messages: *"How alerting do you consider the "{Slow Down/Fill Gas/Passing by a Point of Interest}" message? (1= "Not alerting at all"; 7= "Very alerting")"*. Afterwards, another three questions were asked about the perceived alertness level of the scents. Each scent was presented for 5s every time a new *"How alerting do you consider this scent? (1= "Not alerting at all"; 7= "Very alerting")"* question appeared on the second screen. The scent presentation time was enough to make sure that the participants inhale at least once [32]. There were 30s breaks between the questions on scent alertness to avoid scent mixing and lingering (as in [46]). The participants were submitting their ratings by pressing the corresponding key on the numeric keypad and confirming their input by pressing "Enter".

Step 2 started with a *"Please start driving now!"* message shown on the second screen. This was a sign for the participants to start the five minutes long free driving, the purpose of which was to get used to the setup and the driving simulator software. By the end of the free driving phase, the participants received the first scent, which was delivered for 10s. We doubled the delivery time compared to step 1 to make sure the scent reaches participants' nose despite occasional occlusions of the output of the scent-delivery device by participants' hands or parts of the steering wheel. By the end of the scent-delivery, a questionnaire appeared on the second screen: *"Which message could this scent convey? (1-"Slow Down", 2-"Fill Gas", 3-"Passing by a Point of Interest")"*. Participants were giving their responses by pressing the "1", "2", or "3" key on the numeric keyboard. A feedback message was shown on the screen right after the button-press to confirm their input. We instructed the participants about the fact that the scent-delivery was not synchronised with the current driving situation. The same scent-mapping task was repeated two more times (three times in total). There were breaks of two minutes between scent deliveries. To make sure this time was sufficient to avoid scent-mixing and lingering, we included a self-report question at the end of the study, asking the participants if the breaks were long enough to solve these issues. One minute after the third scent-delivery, the *"Please stop driving and leave the simulator!"* message was shown. This meant the participants had to proceed with filling in the demographic questionnaire (the same as in Study 1) outside the simulator.

Results

Here, we present our findings of mapping the scents onto driving-related messages performed in the process of driving.

Participants

A total of 17 participants, with a mean age of 31 years (SD= 6.00, 3 females) volunteered for this study (different subjects than in Study 1). Participants have reported having no olfactory dysfunctions, adverse reactions to strong smells, respiratory problems, or flu, and not being pregnant. They were recruited on an opportunity-sampling basis. The study was approved by the University of Sussex ethics committee. All participants expressed written consent before the experiment.

Scent Mapping onto Messages

To compare the mapping between scents and the driving-related messages set by the participants while driving, we performed a non-parametric analysis of the data. We found statistically significant differences in the mapping preferences (see Figure 8). In particular, the scent of rose has been highly associated with the "Passing by a point of interest" message ($\chi^2(2)= 7.88, p< .01$), which matches the findings of Study 1 (see Figure 5). The scent of peppermint has been equally linked with "Fill gas" and "Slow down" messages ($\chi^2(2)= 5.77, p< .05$), while the scent of lemon has mainly been affiliated with the "Slow down" message (not significant).

These findings are consistent with the results of Study 1, where lemon and peppermint scents were associated with the same messages (see Figure 4). Such results suggest that both lemon and peppermint are good for either the "Slow down" or the "Fill gas" messages, which is in line with the high alertness level of the two messages (see Figure 3) and the alertness ratings of these scents (see Figure 6).

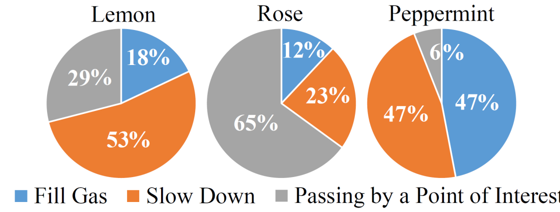

Figure 8: Percentage of subjects having mapped the corresponding scent on one of the three driving-related messages.

Summary

Study 2 has validated the mapping between scents and messages (from Study 1) in the context of driving. This study presents initial findings and creates a new dimension of research within the scope of automotive user interfaces: conveying information by means of the smell inside the car.

DISCUSSION

In this section, we discuss how the results from our studies can inform the design of in-car interaction and experiences.

Levels of Alertness: Clear and Ambivalent Mappings

As expected, the "Fill gas" and "Slow down" messages were clearly perceived as more alerting and urgent than the "Passing by a point of interest" message. Alerting messages were further mapped onto the arousing scents, like lemon and peppermint, which is in line with previous findings on the alerting effect of those two scents [39, 5]. However, despite the expected relaxing effect of lavender [31, 28], in Study 1 participants associated it with alerting and urgent messages. This makes sense, because lavender still is a very intense odour that people can quickly recognise and respond to.

Interestingly, alongside peppermint, lavender was chosen as one of the best scents to convey the "Slow down" message, implicitly advising the driver to calm down (e.g. we speed up when we are too excited or nervous). This thought-provoking effect is in line with the related work on unconscious effects of scents [8, 43]. On contrary, the calming scent of rose clearly showed its relaxing effect. It dominated in the mapping onto the "Passing by a point of interest" message in both of our studies. In Study 1, both this message and the scent of rose were rated most relaxing. Such perception of the rose scent also matches the results from the previous work [20, 15].

It is important to note that the scent of rose was not explicitly dominant in the scent mapping results of Study 1. This could be due to the ambivalent quality of the "Passing by a point of interest" message, which can be interpreted variously. Its exact meaning depends strongly on the context. If I miss one of the points of interest, I might just turn around, or wait for another one. Nevertheless, if the current point of interest is the one I definitely want to visit, I may want an alerting scent to notify me about its proximity. This might be the reason why we found no significant dominance of the rose scent in relation to the "Passing by a point of interest" message at that stage.

A further explanation can be found in the distinction between primary, secondary and tertiary driving tasks. While "Fill gas" and "Slow down" are related to the primary task of driving and are distinctly alerting and urgent, the "Passing by a point of interest" is a message that falls into the category of secondary or even tertiary driving tasks (similar to using the radio described in [37]). A more specific design approach can be considered for such messages (i.e. customised mapping).

Opportunity to Expand the Range of Information

In our studies, we focused on three main messages, which we selected taking into account the level of alertness, and urgency of the information (message) to be conveyed to the driver (see the two-dimensional framework in Figure 3). Based on our findings, this set of messages can be further extended and clustered along primary, secondary, and tertiary tasks for the driver. Other primary tasks could include driving related information such as "Ice on road", "Traffic jam ahead", or "Bad weather alert", whereas notifications in relation to secondary and tertiary tasks could be "Favourite radio station available", "Bakery nearby", "New social event invitation" etc. Later, when we know how to deliver scents to trigger an immediate reaction from the driver, we can also explore messages like "Excessive lane deviation" and "Short inter-vehicle distance".

Other scents, interesting to explore in the scope of conveying primary notifications, could be cinnamon and rosemary, which have already proven their alerting effect in [39, 50]. For secondary and tertiary notifications, we might apply vanilla, ylang-ylang, and caramel, which were classified as relaxing in [14, 21, 9]. A different mapping between the scents and the informative messages might emerge out of future empirical investigations. It would be interesting to see if further hints of unconscious scent associations arise. An example case might be as follows: participants perceive the scent of caramel as intense and map it on the alerting "Traffic jam ahead" message, even though, this scent was labelled as "soothing-peaceful" by Chrea et al. [9]. "Traffic jam ahead" does however implicitly say, we should stay calm (despite the stressful situation).

Furthermore, it is important to mention that we focused on indirect associations in our studies, rather than on the literal mapping between a scent and a driving-relevant message (e.g. "Fill gas" and the scent of petrol, or "Slow down" and the scent of burned rubber). Our study is based on previously established classifications of the selected scents as alerting and relaxing, which engage users on an emotional level. It is well known that scents have a strong and direct connection to emotions and memory [41, 40, 19] and can, therefore, be a powerful medium to elicit and convey information. The use of naturally arising odours (e.g. petrol leak, the smell of burning rubber in case of emergency braking) could also have undesirable effects on the user, or act as a safety hazard. Direct mapping is however interesting to explore in further studies.

Practical Application Considerations

In a real car, it might be relevant to train the driver on the meaning of a specific scent, to reinforce a preferred behaviour (e.g. "Take a break"), just like we were trained to associate traffic signs with certain pieces of information [22]. Prior work by Kuang and Zhang [27] suggests that there is a potential of doing so by means of the conditioning, which was proven to work in a smell enhanced visual motion perception study.

Our findings are not intended to present a well established mapping for the design of a semantic messaging system, but rather to highlight the correspondence between the arousal of the scents and the alertness level of the messages. This motivates the application of scents based on how important, relevant, or salient the driving-related message is.

Challenges

Our research provides a necessary starting point to open up a new interaction design space for HCI. Despite promising findings, further research is needed involving an even larger sample size, extended set of scents, and more messages.

Our driving setup did not enable links between the scent-message combinations and the current situation on the road. The effect of the scent might be stronger if its delivery is synchronised with a certain traffic event or a vehicle status update. Improvement possibilities also include replacing the air tank with a compressor (more feasible in a real car [50]).

Working with the sense of smell raises ethical concerns as it involves the handling of chemicals, but also because scents have a strong association with emotions and memories. This emphasises the need to allow for customisation of olfaction-based interfaces. The same applies to personal and cultural preferences. Further challenges may include smell unfamiliarity, persistence, and "the stimulus problem" [2].

Persistent smells could be eliminated through advancements of the "olfactory white" in the future [48]. We also need to consider the challenge of delivering the scent without invading the olfactory space of the co-driver and the passengers [10]. Moreover, to account for are potential scents that people seated in the car (i.e. drivers and passengers) bring in with them.

Even though the effect of smell on the driving performance and experience has been studied [5, 39], there is a need to investigate these factors within the scope of conveying driving-related information by scents (also in a real driving setting).

CONCLUSION

Our findings show that using olfactory stimuli as an alternative interaction modality in the car is not arbitrary and that participants are able to establish a mapping between specific driving-related messages and scents. Based on the induced alertness level of both the message and the scent, we demonstrated that it is possible to establish a new semantic layer of information delivery for the driver. These insights open up new opportunities to further explore the topic of conveying information using smell in the context of driving and beyond.

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